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by J.H. Noon and E.H. Holt

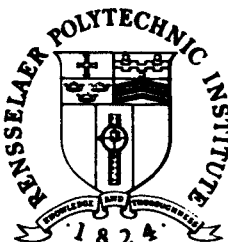
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ABSTRACT

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Measurements at microwave frequencies of the radiation temperature of a nitrogen afterglow plasma show that at early post-discharge times a secondary source of electron heating exists, and that microwave conductivity values calculated on the basis of a Maxwellian form for the electron velocity distribution function are anomalous. The evidence points to non-Maxwellian electron velocity distributions in the early afterglow.

INTRODUCTION

We have carried out measurements on a pulsed discharge in nitrogen, using microwave techniques, which indicate that an equilibrium state is not achieved early in the afterglow, that a secondary source of electron heating exists, and that estimates of electron temperature from radiometer readings, based on an assumed Maxwellian electron velocity distribution, are questionable.

EXPERIMENTAL DETAILS

An X-band hollow-cathode waveguide cell,¹ gated microwave radiometer² and sensitive microwave bridge³ were used to measure the microwave conductivity and the radiation temperature as a function of time in a nitrogen afterglow plasma. The active discharge was initiated by a voltage pulse variable from 3 to 30 microseconds in duration and repeated at 100 c/s rate, and energy input varied from 10^{-4} to 10^{-1} joules. Figure 1 shows measured radiation temperature versus time in the afterglow for different gas pressures and different discharge conditions. In the first few microseconds of the post-discharge period radiation temperature drops rapidly as expected from electron collisions with the neutral molecules. However the radiation temperature rises again with time, reaching a maximum and then falling off slowly.

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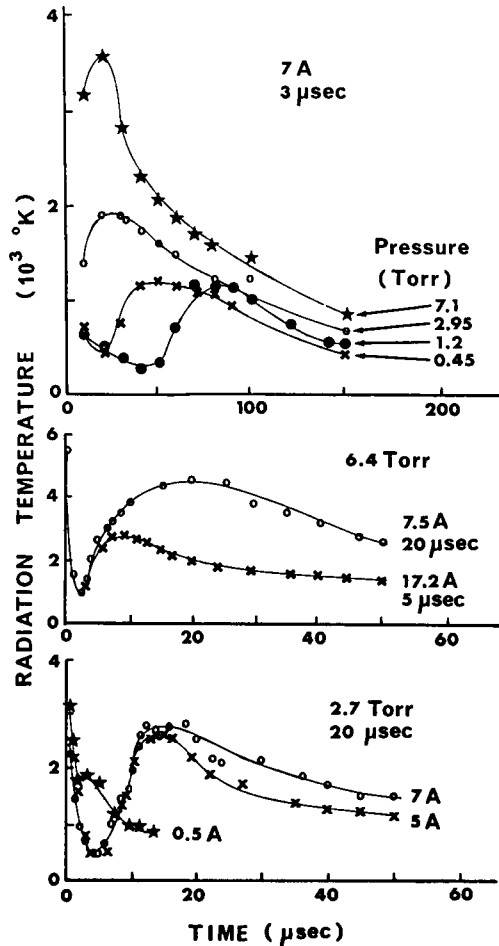


Figure 1. Radiation temperatures measured for different gas pressures and different energy input conditions in the active discharge. Pulse widths from 3 microseconds to 20 microseconds and discharge currents from 0.5 to 17.5 amps were used.

ELECTRON COLLISION PROBABILITY

Calculations by other workers^{4,5} of the probability for momentum transfer P_c of low energy electrons ($< 1\text{ eV}$) in nitrogen as a function of energy, based on microwave conductivity measurements, have not included direct measurement of the electron temperature in the plasma. Results obtained by waveguide transmission⁴ and resonant cavity techniques⁵ differ by a factor of five at low energies. Although the measurements were carried out at different times in the afterglow, both sets of calculations included the assumption of a Maxwellian distribution of electron velocities whether or not the mean electron energy is greater than that of the neutrals.

Our data indicate that calculation of P_c based on the assumption that only 50 microseconds are required for the electrons in the nitrogen afterglow plasma to reach the temperature of the neutral gas⁴ is questionable. This point was raised by Formato and Gilardini⁶ who observed a slow relaxation of electron temperature in nitrogen but did not carry out measurements at times close to the termination of the active discharge.

We have calculated P_c as a function of energy by equating the measured radiation temperature to the electron temperature and have obtained the values of P_c shown in Figure 2. Although the results are generally close to those

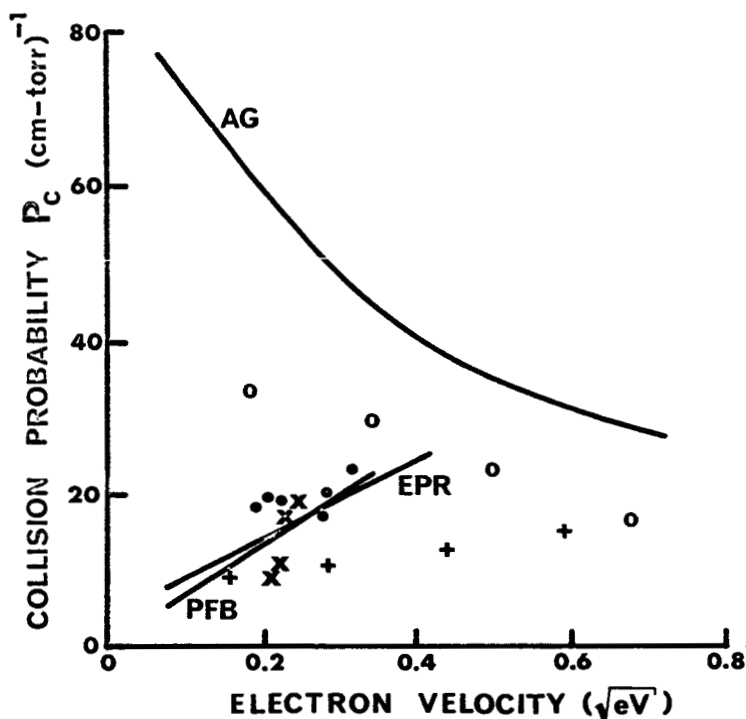


Figure 2. Electron collision probability for momentum transfer (P_c) versus electron velocity. AG Anderson and Goldstein,⁶ PFB Phelps, Fundingsland and Brown,⁷ EPR Engelhardt, Phelps and Risk.⁸
 x 1.75 torr o 5 torr • 5.6 torr + 6.4 torr.

derived from transport coefficients⁷ and resonant cavity measurements⁵ they show a wide scatter. Furthermore investigation of the behavior of the conductivity ratio σ_r/σ_i , (Figure 3), reveals that it is a multi-valued function of the radiation temperature instead of decreasing monotonically. A calculation shows that electron-ion collisions cannot explain the effect at these temperatures (approximately 2000°K). The most likely explanation is that the radiation temperature cannot be equated to the electron temperature and that the form of the electron velocity distribution is not Maxwellian in the early post-discharge period, as assumed in the calculations.

DISCUSSION OF RADIATION TEMPERATURE RESULTS

The fact that the energy input into the active discharge determines the amount of electron heating in the afterglow is shown clearly in Figure 1. This may help to explain why Formato and Gilardini,⁶ using 10 microsecond pulse-widths and currents of order 1 amp. observed a slow decay in the radiation temperature (which they called the "electron temperature") whilst Mentzoni and Row,⁸ using what they refer to as a mildly driven discharge found much more rapid electron relaxation times in agreement with a calculation based on both the elastic electron-molecule collisions and inelastic electron excitation of low-lying rotational levels of the molecule.

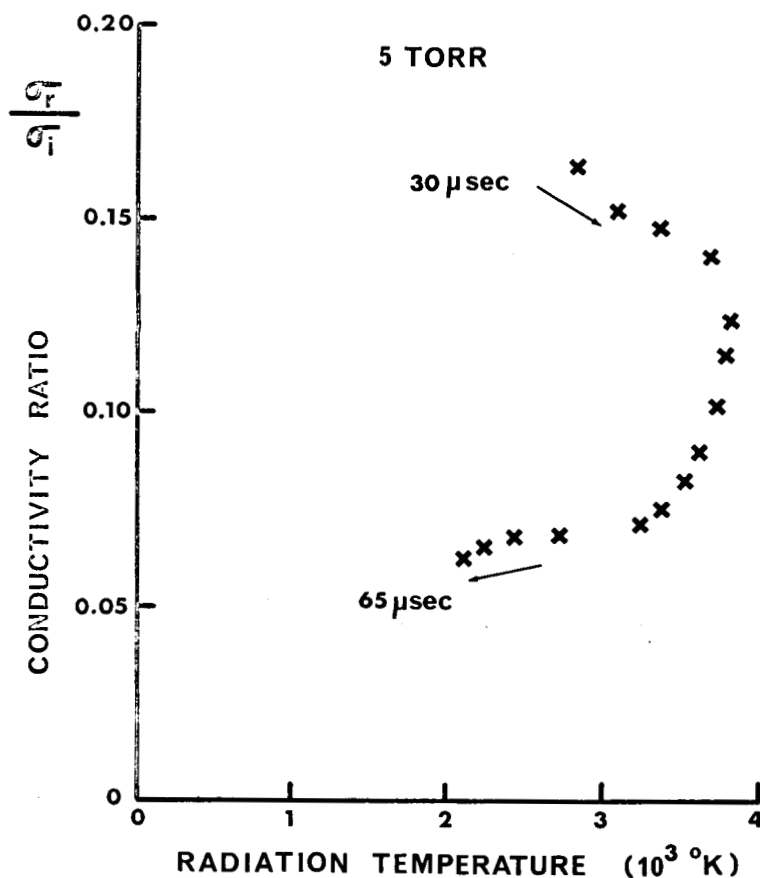


Figure 3. Ratio of real and imaginary parts of the microwave conductivity (σ_r/σ_i) plotted as a function of radiation temperature for post-discharge times ranging from 30 to 65 microseconds. This should fall off monotonically but does not do so, indicating that the calculations based on an assumed Maxwellian distribution are incorrect.

A significant feature of Figure 1 is the rise in radiation temperature which occurs some microseconds after the initial fall following termination of the active discharge. It is not necessary to postulate a delayed secondary source of electron heating in the afterglow of the pulsed nitrogen discharge since departures from a Maxwellian electron velocity distribution could well be the explanation. However the mechanism of energy interchange between electrons and other plasmas constituents is not clear.

Electron-ion recombination, although removing low energy electrons preferentially and thus increasing the average electron energy, could not explain the observed effect. Three possible sources of energetic electrons with nitrogen afterglow have been suggested: (1) energy from molecular dissociation being fed back to the electrons as neutral atoms recombine,⁹ (2) vibrationally excited molecular states coupling with electrons,^{10,11} (3) energy given to electrons from collisions involving metastable states.^{6,12} Further experiments are in progress which are intended (a) to gain direct information about the actual form of the electron velocity distribution function

in the afterglow, using a microwave technique,¹³ and (b) to study the effect of a small proportion of a foreign gas, such as CO₂, on the radiation temperature of the nitrogen plasma and thus establish which of the suggested mechanisms is the source of energetic electrons in the nitrogen afterglow.

REFERENCES

1. E. H. Holt, K. C. Stotz, "Plasma Waveguide Cell for Afterglow Measurements," Rev. Sci. Inst. 34, 1285 (1963).
2. W. C. Taft, K. C. Stotz, E. H. Holt, "A Gated Radiometer for Plasma Afterglow Studies," IEEE Trans. IM 12, 90 (1963).
3. J. Ajello, "The Probability of Collision for Momentum Transfer of Slow Electrons in a Nitrogen Plasma Afterglow," NASA CR 104 (1964); K. C. Stotz, "Investigation of Plasma Afterglows with Application in Nitrogen," NASA TN D-2226 (1963).
4. J. M. Anderson, L. Goldstein, "Interaction of Electromagnetic Waves of Radio-frequency in Isothermal Plasmas," Phys. Rev. 100, 1037 (1955).
5. A. V. Phelps, O. T. Fundingsland, S. C. Brown, "Microwave Determination of the Probability of Collision of Slow Electrons in Gases," Phys. Rev. 84, 559 (1957).
6. D. Formato, A. Gilardini, Ionization Phenomena in Gases, "Microwave Determinations of Afterglow Temperatures and Electron Collision Frequencies in Nitrogen," (Proc. of Fourth Internat. Conf.) Vol. 1, 99, North Holland (1960).
7. A. G. Engelhardt, A. V. Phelps, C. G. Risk, "Determination of Momentum Transfer and Inelastic Collision Cross-Sections for Electrons in Nitrogen Using Transport Coefficients," Phys. Rev. 135, A156 (1964).
8. M. H. Mentzoni, R. V. Row, "Rotational Excitation and Electron Relaxation in Nitrogen," Phys. Rev. 130, 2312 (1963).
9. E. A. McLennan, L. Goldstein, "Atomic Density Measurements in O₂, N₂, and H₂ Afterglow Plasmas," AFCRL 66-88 (1966);
E. A. McLennan, "Atomic-Density Measurements in Nitrogen, Oxygen, and Hydrogen Afterglow Plasmas," Bull. Am. Phys. Soc. 11, 504 (1966).
10. I. R. Hurle, "On the Thermal Energy Transfer between Free Electrons and Molecular Vibration," J. Chem. Phys. 41, 3592 (1964).
11. A. V. Phelps, private communication.
12. J. A. Van Lint, "Ionization Afterglow Measurements on Nitrogen," IEEE Trans. NS-11, 266 (1964).
13. H. Fields, G. Bekefi, S. C. Brown, "Microwave Emission from Non-Maxwellian Plasmas," Phys. Rev. 129, 506 (1963).